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Winter Wheat Responses to Surface and Deep Tillage on the Southeastern Coastal Plain

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ABSTRACT

Conservation tillage practices have seldom been used to produce winter wheat (*Triticum aestivum* L.) on the U.S. southeastern Coastal Plain, primarily because of inadequate planting equipment and the need for deep tillage. Despite improved equipment, little is known about the effects of surface and deep tillage (ST and DT) systems on winter wheat development and grain yield on the Coastal Plain. Objectives of this 2-yr study were to (i) determine whether ST affects the grain yield response of winter wheat to DT and (ii) examine the effects of ST and DT on winter wheat development. The soil was a Goldsboro loamy sand (fine-loamy, siliceous, thermic Aquic Kandiudult). Treatments were ST (disked twice or no surface tillage) and DT (deep tilled using a ParaTill or no deep tillage). Averaged over years and levels of DT, the number of emerged seedlings was 16% less with no ST than with disking. With DT, the number of heads per square meter was similar for the two levels of ST treatment, indicating that wheat grown with no ST produced more heads per plant than with disking. Soil water contents were usually lower in 1995 than in 1994 for all treatments (<2 g kg^{-1} prior to inflorescence emergence in 1995). Aboveground dry weights near inflorescence emergence, kernel no. m^{-2}, and grain yields averaged 39, 26, and 22% less, respectively, in 1995 than in 1994. Deep tillage increased aboveground dry weight, kernel no. m^{-2}, and grain yield more for wheat in no-surface-tillage plots than in disked plots. When deep tilled, ST had no effect on grain yield in 1994, but yields were 25% greater for wheat grown with no ST in the drier year of 1995. There may be no need to disk the soil if DT is performed and proper planting equipment is used to produce winter wheat on the southeastern Coastal Plain. Yield increases due to DT in this region should be greater with no ST than with disking.

DROUGHT STRESS frequently reduces the economic yield of summer crops on the sandy Coastal Plain of the USA. For winter crops such as wheat, the severity of drought stress is usually less, since precipitation generally exceeds evapotranspiration during the winter and early spring months (15). As the wheat growing season progresses, drought stresses can occur during both the stem elongation and, more frequently, during the grain-filling stages of wheat development (3,4,5). Soil water contents usually decrease rapidly during those growth stages, even in years with normal amounts of rainfall (3,4).

By leaving more than 30% of the soil surface covered with residues, conservation tillage may reduce the severity of drought stress that occurs during the growing season. For many soils, surface residues can enhance crop productivity by increasing rainfall infiltration into the root zone (1,2), reducing water runoff (12,14), decreasing soil losses (14), and improving soil tilth (10,11). Surface residues may also improve soil water contents by decreasing soil temperature, impeding the diffusion of water vapor from the soil surface, acting as an absorbant for water vapor diffusing from the soil, and reducing wind velocity at the soil surface (7,17). However, it is not known whether using conservation tillage practices to produce winter wheat will improve soil water contents on the Coastal Plain.

Deep tillage is usually recommended in this region, because many soils contain a tillage pan and/or a naturally forming hardpan just above the clay subsoil (16). Disruption of these compacted layers promotes faster and deeper root growth into the subsoil. Growers traditionally deep till in the fall before planting wheat using equipment that causes significant incorporation of surface residues. Because the soil near the seed may be more compacted in no-surface-tillage systems, compared with disking, fracturing the soil with deep tillage may increase early-season root growth and seedling vigor more in no-surface-tillage systems. There are several deep tillage devices available, such as the ParaTill (AgEquipment Group L.P., Lockney, TX[1]) (9), that cause little incorporation of surface residues and so could be used in conservation tillage systems. Currently, little is known about the effects of surface and deep tillage systems on wheat development and grain yield on the Coastal Plain. Our objectives were to (i) determine whether grain yield increases due to deep tillage are greater in no-surface-tillage systems than in systems where the soil surface is disked and (ii) examine the effects of surface and deep tillage on winter wheat development.

MATERIALS AND METHODS

Site Description and Cultural Practices

Soft red winter wheat (Northrup King cv. Coker 9134) was grown with two levels of surface tillage and two levels of deep tillage during the 1993–1994 and 1994–1995 growing seasons at the Pee Dee Research and Education Center near Florence, SC. Northrup King Coker 9134 was selected for this study because of its high grain yield potential, high straw yield, and good disease and insect resistance (6). Conventionally tilled soybean [*Glycine max* (L.) Merr.] was grown prior to the first year of the study. After wheat harvest in 1994, soybean was grown using 19-cm row spacings and the same surface tillage practices as used to produce the wheat. Plots were not deep tilled for the soybean crop. Wheat plots were reestablished onto the same plots in the fall of 1994 using the

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[1]Reference to a trade or company name is for specific information only and does not imply approval or recommendation of the company or product by Clemson University or the USDA-ARS to the exclusion of others that may be suitable.

Abbreviations: DT, deep tillage; FGS, Feekes growth stage; ST, surface tillage; SWC, soil water content.

same levels of surface and deep tillage as used the previous year.

Phosphorus and potassium fertilizers and lime were broadcast applied to all plots at rates based upon soil test results. No-surface-tillage plots were sprayed with glyphosate [*N*-(phosphonomethyl)glycine] at a rate of 1.12 kg a.i. ha^{-1} before planting. Wheat seeds were planted on 18 and 23 November in 1994 and 1995, respectively, using a John Deere 750 grain drill. Seventy-three seeds per meter of crop row were planted in rows spaced 0.19 m apart oriented in a north-south direction.

Ammonium nitrate was broadcast onto all of the plots immediately after planting at a rate of 34 kg N ha^{-1} using a 3-m-wide Gandy fertilizer spreader (Gandy Co., Owatonna, MN). Ammonium nitrate was also applied at a rate of 56 kg N ha^{-1} to the plots at FGS 5.0 (stem erect growth stage; 13).

Treatments Applied

Treatments were the four combinations of surface tillage (disked and no surface tillage) and deep tillage (deep tilled and no deep tillage). Each treatment was replicated four times. Disked plots were disked twice before planting. After disking, the appropriate plots were deep tilled using a four-shanked Tye ParaTill set to a depth of 41 cm (top of B soil horizon). Shanks were mounted as opposed pairs spaced 71 cm apart. A serrated cutting coulter was mounted in front of each shank. All plots were 3 m wide (16 rows) and 15 m long.

Parameters Evaluated

Plant residue cover was determined using a line-transect method. Immediately after planting, a measuring tape was stretched diagonally across each plot. This tape was checked every 30 cm to see whether plant residue greater than 0.25 cm wide was touching the tape. Residue coverage was not measured on disked plots in 1994, since little residue remained on the soil surface after disking. Seedling emergence was estimated by counting the number of seedlings per 0.30 m of crop row 3 wk after planting. Seedlings were counted in each of the six center rows at three locations in each plot (total of 18 0.30-m row segments per plot).

Gravimetric soil water content was monitored beginning near FGS 6.0 (jointing) by placing gypsum electrical conductivity blocks at a depth of 23 cm below the crop row in 1994 and 23 and 46 cm below the crop row in 1995. Two blocks were placed at each soil depth in each plot. Soil temperature data were collected at each sampling depth and date with dial-type soil thermometers so that gypsum block readings could be corrected for differences in soil temperature. Using a small growth chamber, a calibration curve of soil water content vs. block conductivity reading was made for every 2.8°C between 10 and 24°C.

Changes in aboveground dry weight were measured during the wheat growing season by harvesting a 30-cm section of crop row from each of the five center rows of each plot approximately every 10 d between FGS 5.0 (stem erect) and 10.5 (inflorescence emergence). All samples were dried at 75°C for 2 d and weighed. Date of 100% inflorescence emergence (FGS 10.5) was determined by conducting daily ratings for the percentage of tillers within a 0.8-m^2 subsection of each plot that had inflorescences not touching the ligules of the flag leaf.

At harvest maturity (kernel hard stage) in 1994, a 1-m-long section of crop row was hand-harvested from the 7th, 9th, and 11th rows of each plot to determine grain yield components. After sample collection, plots were combine-harvested to determine grain yield. In 1995, a 1-m-long section of crop row was hand-harvested from each of the six center rows to determine grain yield and grain yield components. In both years, the number of fertile (grain-bearing) heads was counted after sample harvest, and the grain from each sample was threshed, cleaned, dried at 75°C for 2 d, and weighed. Individual kernel weight was determined by counting, drying, and weighing 200 kernels from each sample. Kernel number per head and kernel number per square meter were calculated from the head number, grain yield, and individual kernel weight data. Harvest index was calculated by dividing the grain yield of each sample by the biological yield (total aboveground dry weight). Grain yield data were converted to a 130 g kg^{-1} water basis.

Rainfall and air temperature data were collected during the growing season at a weather station about 200 m from the experimental field. Growing degree days were calculated by averaging the daily maximum and minimum air temperatures. A maximum threshold of 30°C was used for the daily high temperatures and a minimum threshold of 0°C was used for the daily lows. A base temperature of 0°C was used for degree day calculations.

Statistical Analyses

All plant development, soil water content, grain yield, and yield component data were subjected to analysis of variance for a randomized complete block design with four replications. Polynomial regression equations were developed to describe the increase in aboveground dry weight with time for each treatment. An LSD (0.05) was calculated for the residue cover, seedling number, grain yield, and yield component data to compare interaction means when the surface tillage × deep tillage interaction effect was significant at the 0.05 probability level.

RESULTS AND DISCUSSION

Rainfall was near normal during the spring of 1994 and well-above normal until about FGS 10.5 in 1995 (Fig. 1). Rainfall was also above normal between planting and 31 December in 1994, but near normal during that time in 1993 (data not shown). A dry period began near Day 70 in 1995 and continued throughout most of the grain-filling period (Fig. 1). Accumulated rainfall was near normal by the end of the 1995 growing season. Air temperatures were near normal in both years, as indicated by the near-normal accumulation of growing degree days in 1994 and 1995 (Fig. 1). Dates of FGS 10.5 were also similar for all treatments and years (data not shown).

Because of the extended dry period in 1995, SWCs at the 23-cm depth were less in 1995 than in 1994 after Day 90 (Fig. 2). In both years, SWCs at the 23-cm depth prior to FGS 10.5 (inflorescence emergence) were usually greater in the deep-tilled plots than in the plots receiving no deep tillage. Deep tillage had no effect on SWC after FGS 10.5. These results indicate that fracturing compacted layers with deep tillage allows winter wheat to be less reliant on topsoil water before inflorescence emergence. Differences in SWC between levels of deep tillage were greater in the no-surface-tillage plots than in the disked plots in 1995, but not in 1994. For both levels of deep tillage, SWCs at the 46-cm depth in 1995 were lower in the no-surface-tillage plots than in the disked plots throughout the measurement period (Fig. 2). These trends suggest that using conservation tillage

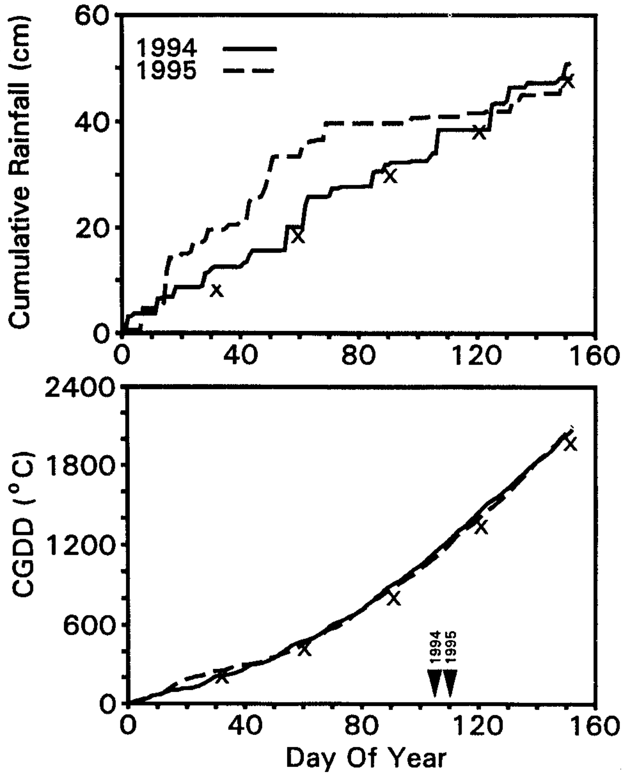

Fig. 1. Cumulative rainfall and cumulative growing degree days for the 1994 and 1995 spring growing seasons. Crosses indicate normal cumulative rainfall and growing degree days, based on monthly 30-yr averages (1951–1980). Arrows indicate average date of 100% inflorescence emergence (FGS 10.5) over all treatments in 1994 and 1995.

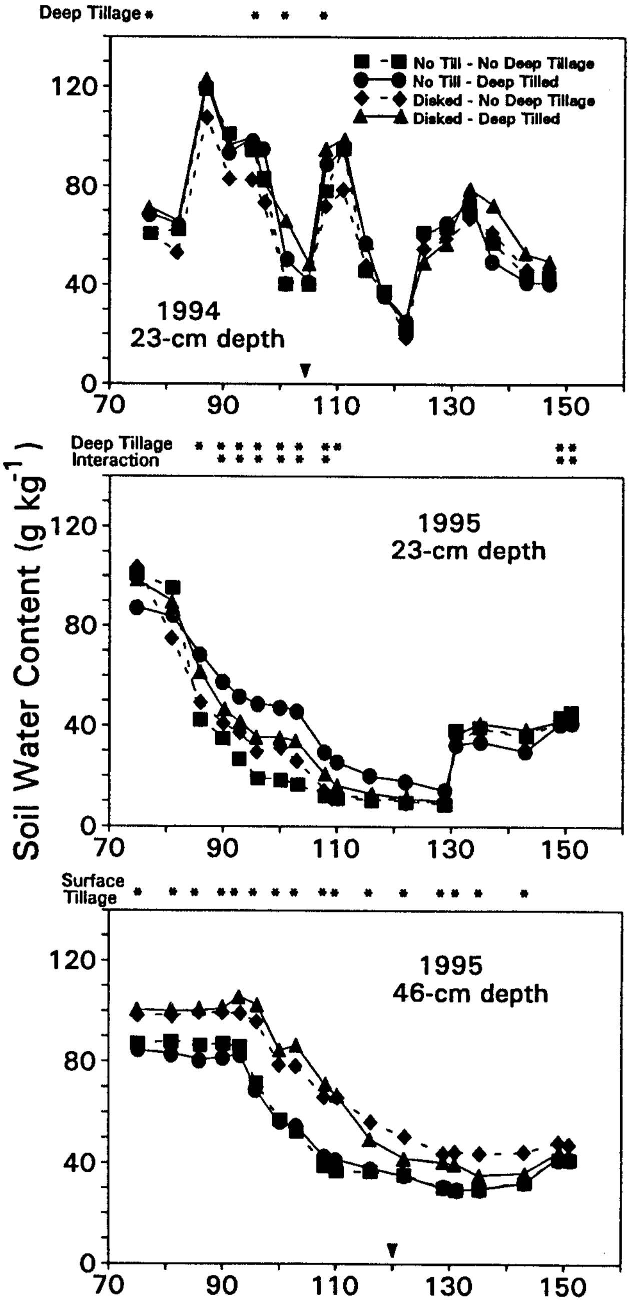

Fig. 2. Gravimetric soil water contents at the 23-cm depth in 1994 and 1995 and at the 46-cm depth in 1995 for the two levels of surface tillage and two levels of deep tillage. Arrows indicate average date of 100% inflorescence emergence (FGS 10.5) over all treatments in 1994 and 1995. * Significant treatment effect at the 0.05 probability level.

practices may favor deeper soil water extraction in winter wheat, especially in dry years.

Although there was little plant residue on the soil surface of the disked plots, residue cover in the no-surface-tillage plots averaged 87% over years and levels of deep tillage (Table 1). Planting wheat using no surface tillage decreased plant emergence in both years, as indicated by the 16% fewer seedlings in the no-surface-tillage plots than in the disked plots (Table 1). Deep tillage decreased residue cover in the no-surface-tillage plots an average of 14% over both years, but had no effect on seedling number. Karlen and Gooden (8) also found that wheat plant populations were lower with no-surface-tillage systems than with disked systems. They attributed this response to inadequate planting equipment available to growers at the time. Compared with disking, they proposed that lower grain yields of wheat grown with no surface tillage were the result of lower plant populations. As discussed below, lower seedling numbers with no surface tillage in our study did not result in lower yields, especially when the plots were deep tilled.

Aboveground dry weights prior to grain fill were generally greater in the wetter year of 1994 than in 1995 (Fig. 3). Wheat in the no-surface-tillage and disked plots had similar aboveground dry weights when the plots were deep tilled in 1994, but wheat grown with no surface tillage had greater dry weights than wheat in the disked plots in the drier year of 1995. Aboveground dry weights were increased by deep tillage in both the disked and no-surface-tillage plots in 1994 and 1995, but the increases were greater for wheat grown with no surface tillage on most sampling dates. Similar treatment effects were found for leaf area indices measured on several dates prior to FGS 10.5 in 1994 and 1995 (data not shown).

Fertile head number per square meter was usually the same or greater for wheat in the no-surface-tillage plots

Table 1. Percentage of soil surface covered by residues and seedling number as affected by surface and deep tillage treatments in 1994 and 1995.

Tillage		Residue cover		Seedling no.	
Surface	Deep	1994	1995	1994	1995
		%		no. m^{-2}	
No-till	No	89.5	97.4	199	269
No-till	Yes	74.5	86.5	207	272
Disked	No	–†	20.5	286	292
Disked	Yes	–	19.9	266	283
Effect					
Surface tillage (ST)		–	**	**	*
Deep tillage (DT)		**	*	NS	NS
ST × DT		–	*	NS	NS
LSD (0.05)‡		–	7.8	NS	NS

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Residue cover data not collected from disked plots in 1994.
‡ LSD for comparison of interaction means.

than for wheat in the disked plots, especially when the plots were deep tilled (Table 2). Since fewer plants emerged when no surface tillage was compared with disking, wheat grown with no surface tillage must have compensated for its fewer plant numbers by producing more heads per plant when the plots were deep tilled. The ability of wheat to tiller more when plant numbers are low suggests that small reductions in seedling emergence with no-surface-tillage systems should not be a major factor limiting wheat yields.

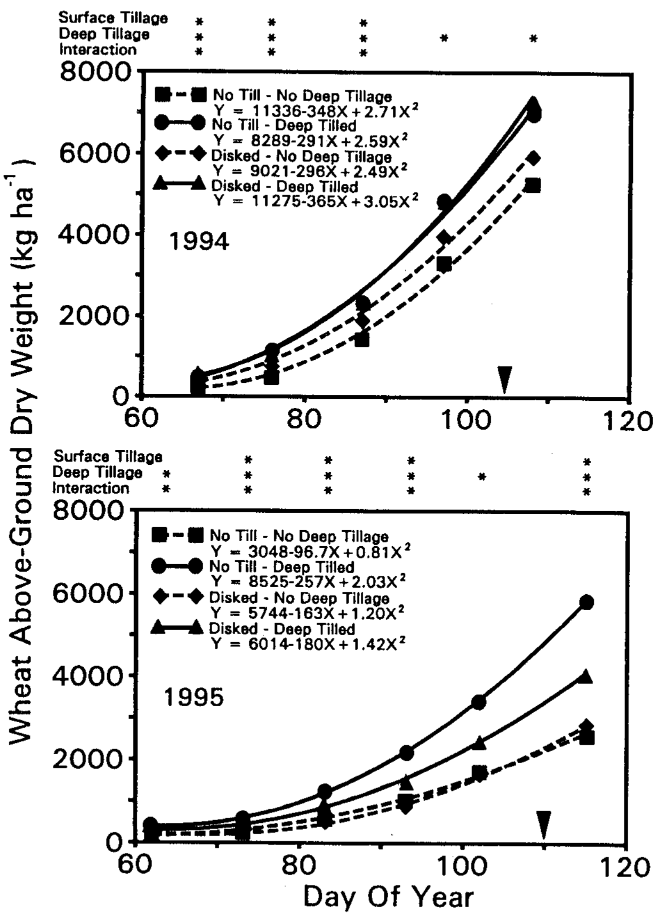

Fig. 3. Wheat aboveground dry weights as a function of time for the two level of surface tillage and two levels of deep tillage in 1994 and 1995. Arrows indicate average date of 100% inflorescence emergence (FGS 10.5) over all treatments in 1994 and 1995. * Significant treatment effect at the 0.05 probability level.

Table 2. Wheat grain yield components as affected by surface tillage and deep tillage treatments in 1994 and 1995.

Tillage		Head no.		Kernel no.		Kernel wt.	
Surface	Deep	1994	1995	1994	1995	1994	1995
		no. m^{-2}		no. $head^{-1}$		mg $kernel^{-1}$	
No-till	No	443	356	28.0	26.6	26.9	26.1
No-till	Yes	556	391	28.0	34.0	28.3	27.2
Disked	No	550	315	25.9	28.3	25.9	25.7
Disked	Yes	549	371	27.3	29.0	28.7	27.0
Effect							
Surface tillage (ST)		**	*	NS	NS	NS	NS
Deep tillage (DT)		**	**	NS	**	**	**
ST × DT		**	NS	NS	*	NS	NS
LSD (0.05)†		29	NS	NS	3.3	NS	NS

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† LSD for comparison of interaction means.

There were no treatment effects on kernel number per head in 1994 (Table 2). In 1995, deep tillage resulted in 2 and 28% more kernels per head for wheat grown with and without disking, respectively. Frederick and Camberato (4) reported that wheat kernel number per head was reduced when SWC prior to FGS 10.5 decreased to values similar to those found in our 1995 study. Water depletion at deeper soil depths was greater with than without deep tillage in our 1995 study. This greater water availability with deep tillage probably reduced the severity of plant water stress during head development, resulting in more kernels per head. The benefit from deep tillage on kernel number per head was greater for wheat in the no-surface-tillage plots than for wheat in the disked plots.

Deep tillage increased kernel weight an average of 6% over both years and both levels of surface tillage (Table 2). Frederick and Camberato (4) reported that drought stress decreased kernel weight by reducing the length of the grain-filling period. They also found that drought stress had a greater effect on kernel number than on kernel weight. Data from the current study support these findings; deep tillage resulted in greater increases in kernel number per square meter (Table 3) than in kernel weight (Table 2).

Table 3. Wheat grain yield, harvest index, and kernel number per unit area as affected by surface tillage and deep tillage treatments in 1994 and 1995.

Tillage		Grain yield		Harvest index		Kernel no.	
Surface	Deep	1994	1995	1994	1995	1994	1995
		kg ha^{-1}		kg kg^{-1}		no. m^{-2}	
No-till	No	3628	2844	0.419	0.454	12 403	9 481
No-till	Yes	4515	4158	0.439	0.484	15 862	13 272
Disked	No	3988	2629	0.418	0.458	14 262	8 913
Disked	Yes	4476	3335	0.426	0.452	14 938	10 753
Effect							
Surface tillage (ST)		**	**	NS	*	NS	*
Deep tillage (DT)		**	**	NS	NS	**	**
ST × DT		**	*	NS	*	**	*
LSD (0.05)†		249	435	NS	0.020	2 135	1 351

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† LSD for comparison of interaction means.

Grain yield differences between years and among treatments were similar to those found for aboveground dry weights. Grain yields for the two levels of surface-tillage treatment were similar when plots were deep tilled in 1994 (Table 3); however, wheat yield of the disked plots in 1994 was greater than that of the no-surface-tillage plots when the plots were not deep tilled. In the drier year of 1995, grain yields were greater without disking than with disking, especially when the plots were deep tilled. These results indicate that the greatest yield benefit from using no surface tillage occurs during dry growing seasons. Greater residue coverage in 1995 than in 1994 (Table 1) may also partially explain why yields were greater without disking than with disking when the plots were deep tilled in 1995, but not in 1994.

Greater wheat yield in the no-surface-tillage plots that were deep tilled in 1995 was associated with a greater harvest index (Table 3). There were few other treatment effects on harvest index in either year, suggesting that grain yield differences among treatments were similar to those of the aboveground dry weights. Over both years, grain yield responses to the different treatments were significantly correlated with those of kernel number per square meter ($r = 0.98$) ($n = 32$), but less so with those of individual kernel weight ($r = 0.79$).

In summary, deep tillage resulted in yield increases in 1994 and 1995 by increasing head number per plant and, to a lesser degree, kernel weight. Kernel number per head was also increased by deep tillage when drought occurred prior to FGS 10.5 in 1995. In both years, yield and kernel number per square meter were increased by deep tillage more in the no-surface-tillage plots than in the disked plots.

Using conservation tillage reduced seedling emergence but resulted in more fertile heads per plant, compared with disking, especially when growing conditions were improved with deep tillage. Our data suggest that using conservation tillage for winter wheat production on the southeastern Coastal Plain has the potential to increase wheat yields if prolonged periods of drought stress occur prior to FGS 10.5. Even if drought does not occur during that time, grain yields with conservation tillage should be similar to those obtained with disking if modern planting equipment and deep tillage are used.

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REFERENCES

1. Bruce, R.R., S.R. Wilkinson, and G.W. Langdale. 1987. Legume effects on soil erosion and productivity. p. 127–138. *In* J.F. Power (ed.) Role of legumes in conservation tillage systems. Soil Conserv. Soc. Am., Ankeny, IA.
2. Dick, W.A., D.M. Van Doren, Jr., G.B. Triplett, Jr., and J.E. Henry. 1987. Influence of long-term tillage and rotation combinations on crop yields and selected soil parameters: I. Results obtained for a Mollic Ochraqualf soil. Res. Bull. 1180. Ohio State Univ. Agric. Res. and Dev. Ctr., Wooster.
3. Frederick, J.R., and J.J. Camberato. 1994. Leaf net CO_2-exchange rate and associated leaf traits of winter wheat grown with various spring nitrogen fertilization rates. Crop Sci. 34:432–439.
4. Frederick, J.R., and J.J. Camberato. 1995. Water and nitrogen effects on winter wheat in the southeastern Coastal Plain: I. Grain yield and kernel traits. Agron. J. 87:521–526.
5. Frederick, J.R., and J.J. Camberato. 1995. Water and nitrogen effects on winter wheat in the southeastern Coastal Plain: II. Physiological responses. Agron. J. 87:527–533.
6. Graham, W.D., R.J. Gambrell, and C.W. Myers. 1994. Performance of small grain varieties in South Carolina: 1994. S.C. Agric. Exp. Stn. Circ. 175.
7. Greb, B.W. 1966. Effect of surface-applied wheat straw on soil water losses by solar distillation. Soil Sci. Soc. Am. Proc. 30:786–788.
8. Karlen, D.L., and D.T. Gooden. 1987. Tillage systems for wheat production in the southeastern Coastal Plain. Agron. J. 79:582–587.
9. Karlen, D.L., W.J. Busscher, S.A. Hale, R.B. Dodd, E.E. Strickland, and T.H. Garner. 1991. Drought condition energy requirement and subsoiling effectiveness for selected deep tillage implements. Trans. ASAE 34:1967–1972.
10. Langdale, G.W., W.L. Hargrove, and J. Giddnes. 1984. Residue management in double-crop conservation tillage systems. Agron. J. 76:689–694.
11. Langdale, G.W., R.L. Wilson, Jr., and R.R. Bruce. 1990. Cropping frequencies to sustain long-term conservation tillage systems. Soil Sci. Soc. Am. J. 54:193–198.
12. Langdale, G.W., A.P. Barnett, R.A. Leonard, and W.G. Fleming. 1979. Reduction of soil erosion by the no-till system in the southern Piedmont. Trans. ASAE 22:82–86.
13. Large, E.C. 1954. Growth stages in cereals: Illustrations of the Feekes scale. Plant Pathol. 3:128–129.
14. Mills, W.C., A.W. Thomas, and G.W. Langdale. 1986. Estimating soil loss probabilities for southern Piedmont cropping–tillage systems. Trans. ASAE 29:948–955.
15. Nelson, L.B., and R.E. Uhland. 1955. Factors that influence loss of soil applied fertilizers and their probable importance in sections of the United States. Soil Sci. Soc. Am. Proc. 19:492–496.
16. NeSmith, D.S., W.L. Hargrove, D.E. Radcliffe, E.W. Tollner, and H.H. Arioglu. 1987. Tillage and residue management effects on properties of an Ultisol and double-cropped soybean production. Agron. J. 79:570–576.
17. Wilhelm, W.W., H. Bouzerzour, and J.F. Power. 1989. Soil disturbance-residue management effect on winter wheat growth and yield. Agron. J. 81:581–588.